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MTF measurement and analysis of linear array HgCdTe infrared detectors

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HIGHLIGHTS

- A guard-ring HgCdTe detector was designed to effectively suppressing crosstalk.
- A modified slanted-edge method to measure the MTF of linear array HgCdTe detectors.
- The MTF of linear HgCdTe infrared detectors have been calculated and discussed.

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ABSTRACT

The slanted-edge technique is the main method for measurement detectors MTF, however this method is commonly used on planar array detectors. In this paper the authors present a modified slanted-edge method to measure the MTF of linear array HgCdTe detectors. Crosstalk is one of the major factors that degrade the MTF value of such an infrared detector. This paper presents an ion implantation guard-ring structure which was designed to effectively absorb photo-carriers that may laterally defuse between adjacent pixels thereby suppressing crosstalk. Measurement and analysis of the MTF of the linear array detectors with and without a guard-ring were carried out. The experimental results indicated that the ion implantation guard-ring structure effectively suppresses crosstalk and increases MTF value.

1. Introduction

HgCdTe infrared (IR) detectors are widely used in military, civilian and other fields of infrared imaging systems due to their performance advantage and wide applications over the entire IR band range. Modulation transfer function (MTF) is an important parameter used to characterize the spatial resolution and imaging quality of many types of detectors. However, the MTF value of HgCdTe detectors is seriously degraded by crosstalk, which consists of both optical and electrical crosstalk. The electrical crosstalk that is due to photo-carrier lateral diffusion is the main component of total crosstalk. The electrical crosstalk closely relates to the structure of the device; thus, a reasonable structure design can effectively reduce the photo-carrier lateral diffusion. In this paper an ion implantation guard-ring structure is presented to suppress electrical crosstalk. Several methods for the measurement of the MTF of infrared detectors have been reported in literature. Some of these methods include point spread function [1], slit target [2,3], slanted-edge target [4,5] and random speckle [6,7]. Among these measurement methods, the point-spread function technique requires the size of the point source to be smaller than the pixel of detector. However, with fabricated pixel size becoming smaller and smaller the point-spread function method will meet great challenges. Accurate MTF measurement of detectors requires high-precision slit targets, but it is difficult to align such a slit. The slanted-edge method is widely used; however, it is mainly used in planar array detectors. The random speckle wavelength is determined by laser the light source, and the data processing is complicated.

In this article, an ion implantation guard-ring structure detector is introduced to suppress the crosstalk that seriously reduces the MTF value of HgCdTe infrared detectors. A modified slanted-edge method for measuring the MTF of a linear array HgCdTe infrared detector will be presented. Finally, we will discuss the detailed MTF measurements of a 256 × 1 pixel mid-wave guard-ring structure linear array HgCdTe infrared detector and the same detector without a guard-ring structure.

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2. Guard-ring structure of linear array HgCdTe photodetector

A mid-wave linear array HgCdTe infrared detector with a guard-ring structure [8–11] will be described in this section. The guard-ring structure and without-guard-ring structure are designed and fabricated as illustrated in Fig. 1. Both of the HgCdTe photodiodes [12–14] use the same size wafer and process conditions. These planar type back-illuminated HgCdTe photodiodes with cutoff wavelength at 4.6 μm were fabricated on the N-on-P type ZnS/CdTe/HgCdTe/epitaxy material [15] which was grown by liquid phase epitaxy (LPE). The etching method is dry etching [16].

The HgCdTe photodiode consists of four layers built on a CdZnTe substrate. The first layer is a 2300 Å thick ZnS passivation layer and the second is a 1100 Å thick CdTe passivation layer. A 7 μm P-HgCdTe absorbing layer is followed by 1 μm N-HgCdTe and a 350 μm CdZnTe substrate [17]. The designed size of the PN-junction area was $(28 * 28)\ \mu m^2$. Fig. 2(b) shows the detector with the N implantation guard-ring. The distance between the PN-junction and the guard-ring is 11 μm and the guard-ring contact is connected with the common electrode. The HgCdTe absorption layer absorbs incident photons and generates pairs of photo-carriers which are collected in the near-by PN-junction due to the built-in electric field. However, as the pixel pitch is reduced, the photo-carriers near the PN junction would diffuse freely and may be collected by a neighboring PN-junction to generate cross-talk [18–20], as shown in Fig. 2(a). In the guard-ring structure as shown in Fig. 2(b), some of the freely diffused photo-carriers which are collected by the neighboring PN-junction will be limited within the guard-ring area and be collected by the guard-ring. In this case the two neighboring pixels are relatively isolated, which could effectively decrease crosstalk.

3. Measurement MTF of liner array HgCdTe detector with slanted-edge method

A Slanted-edge technique [21] is one of the most popular methods to measure the MTF of infrared detectors at present. The principle of the method is to use a knife edge crossing over a certain number of pixels by a small angle, then sample the edge response by the number of pixels along the edge. As shown in Fig. 2(a), the half-moon target divides the device from left to right into two parts: the dark area and the bright area. From the start position, the pixel response values of the knife edge region are aligned from left to right along the arrow direction. The advantage of this approach is that it protects the continuity between the sampling data points. By properly adjusting the number of rows and columns in the selected region, a smooth and complete Edge Spread Function (ESF) can be obtained. The derivative of the ESF is the Line Spread Function (LSF), then the MTF can be obtained by calculating the modulus of the Fourier transform for LSF.

In this section, a modified method of slanted-edge measurement for linear array HgCdTe infrared detectors will be introduced. As shown in Fig. 2(b), the lanted-edge method also uses the edge to cross a row of pixels from one side to the other at a certain angle, when the corresponding pixel response values range from completely dark to completely bright. The transition region pixels response values correspond to the step of the ESF curve. Under the same uniformity condition of pixels, this is equivalent to scanning one pixel. The linear pixel response values are projected along the edge direction on the coordinates which are perpendicular to the edge. The pixels response values of the projection constitute the ESF curve.

In Fig. 2(b), P means the pitch, d_h and d_v are the length of horizontal and vertical directions respectively. The actual sampling step length of one pixel is $P * \sin\theta$ where θ is calculated as follows:

$$\theta = \tan^{-1}\left(\frac{d_h}{(N-1) * P + d_v}\right) \tag{1}$$

N is the number of pixels which were crossed over by the edge. The difficulty in using the slanted-edge method to measurement MTF of the linear array HgCdTe infrared detector is to accurately find the pixel response to the edge position, because the linear detector has only a one column pixel so it is difficult to find where the edge is. In order to accurately and quickly sample the data, the half-moon target is transformed into a ‘K’ shape target, as shown in Fig. 3(a).

The ‘K’ shape target can accurately determine the relative position of the linear array HgCdTe detector. Moving the detector when the pixels response values shows a concave curve, the detector position corresponding ‘K’ shape target is located at point 1, as shown in Fig. 3(b). Continuing to move the linear array detector until the pixels response values shows a straight line, it is seen that the detector output corresponds to a ‘K’ shape target located at point 2 in Fig. 3(c). Continuing to move the linear array detector until the pixels response values appears as a step shape, corresponds to the position of the ‘K’ shape target at point 3 in Fig. 3(d).

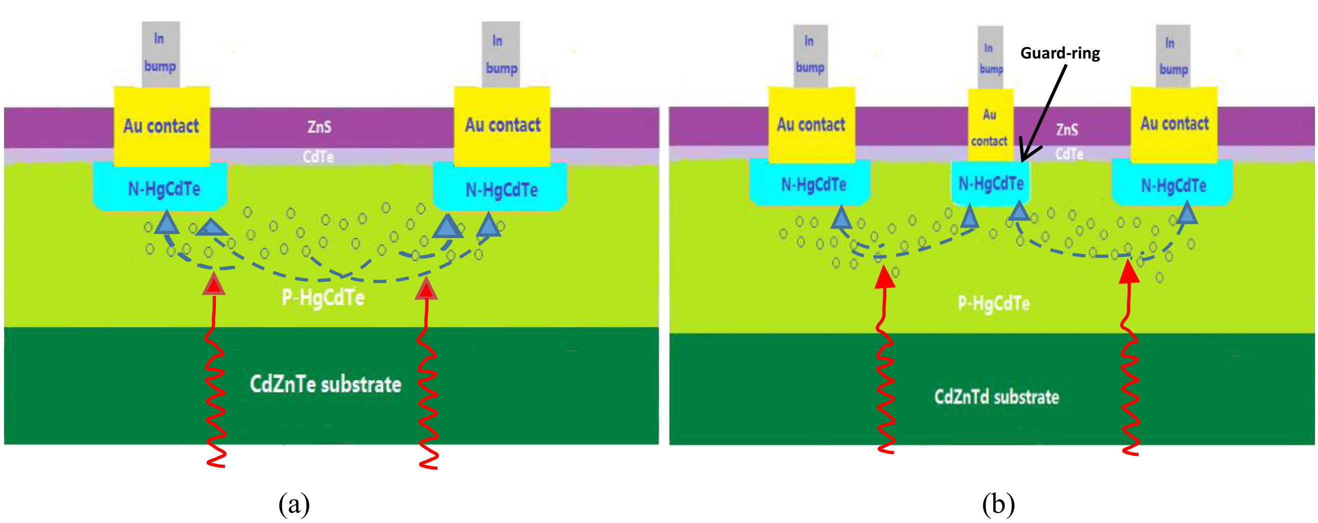

Fig. 1. The figure shows photo-carrier diffusion effect in planar type HgCdTe detectors (a) without guard-ring structure and (b) with guard-ring structure.